



High Capacity Silicon-Graphene Anode for Li-Ion Batteries

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Outline

- XG Sciences
- xGnP[®] graphene nanoplatelets
- Silicon/ graphene Anode for Li-ion batteries
- Graphene sheet heat conductors
- Graphene-coated Al current collectors
- Conclusions

- ✓ Privately held
 - *Licensees & Corp Shareholders: Cabot (US), Hanwha Chemical (K), POSCO (K)*
- ✓ Products:
 - *xGnP® graphene platelets,*
 - *XG Leaf™ sheet,*
 - *Energy Materials, Inks & Coatings*
- ✓ 600+ customers in 32 countries
 - *Overseas distributors Korea, Japan, Taiwan, China and E.U. soon.*
- ✓ Two locations in Lansing, Michigan
 - *80 Ton/year manufacturing (25K ft²)*
 - *Research & Development (14K ft²)*
- ✓ Currently 40 Employees
 - *9 R&D (7 PhDs), 4 Engineering, 4 Management*
- ✓ Spin-off from Michigan State University (2006)

Company mission:

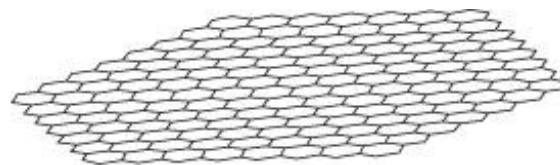
1. Manufacture and sell graphene nanoplatelets as a bulk material in **commercial quantities** at **economical costs**
2. Offer value-added products based on our materials and manufacturing process
 - **Electrode materials** for ultracapacitors and batteries
 - **Films and “papers”** for electronics applications
 - **Coatings, inks and dispersions**



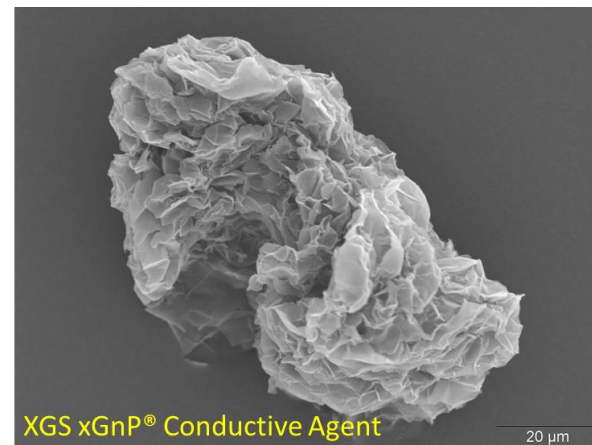
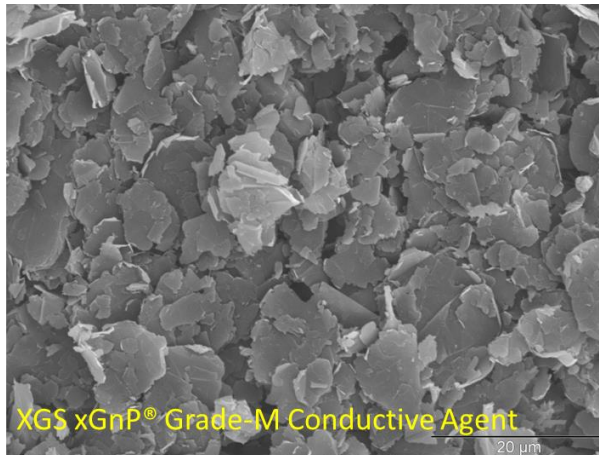
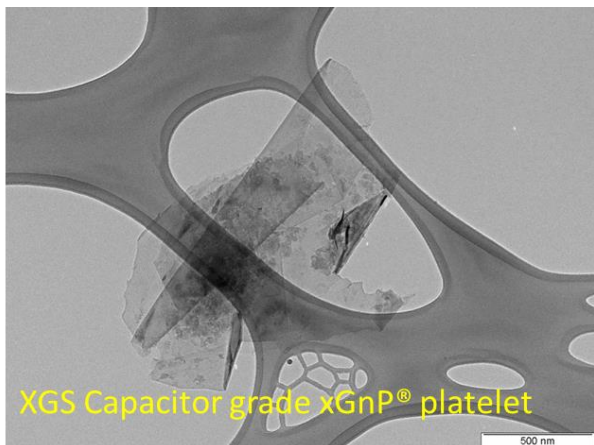
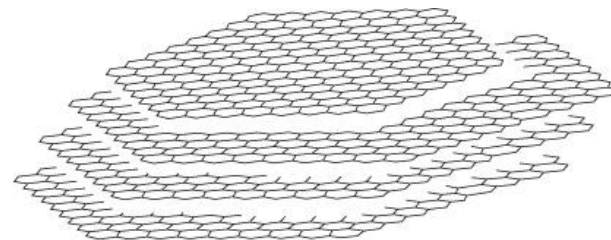
- ✓ Licensees POSCO and Cabot identified XGS **as the world leader**
- ✓ **Low cost manufacturing** process
- ✓ 80+ ton capacity commissioned 2012
 - the largest capacity in the world

What is Graphene?

Graphene - A single layer of carbon atoms, or “an atomic-scale honeycomb lattice of carbon atoms.”



Graphene Nanoplatelet - A particle consisting of multiple layers of graphene.

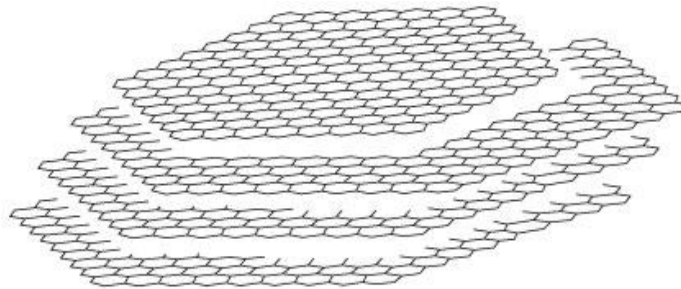


Three different grades for different applications:

- **Grade H:** 80 m²/g – available in 5, 15 or 25 micron diameters
- **Grade M:** 150 m²/g – available in 5, 15 or 25 micron diameters
- **Grade C:** small diameter particles available in 300, 500, 750 m²/g

THICKNESS

1. Mechanical strength
2. Handling
3. Electrical & thermal Properties
4. Loading wt%
5. Cost



DIAMETER

1. Barrier Properties
2. Mechanical Properties
3. Cost

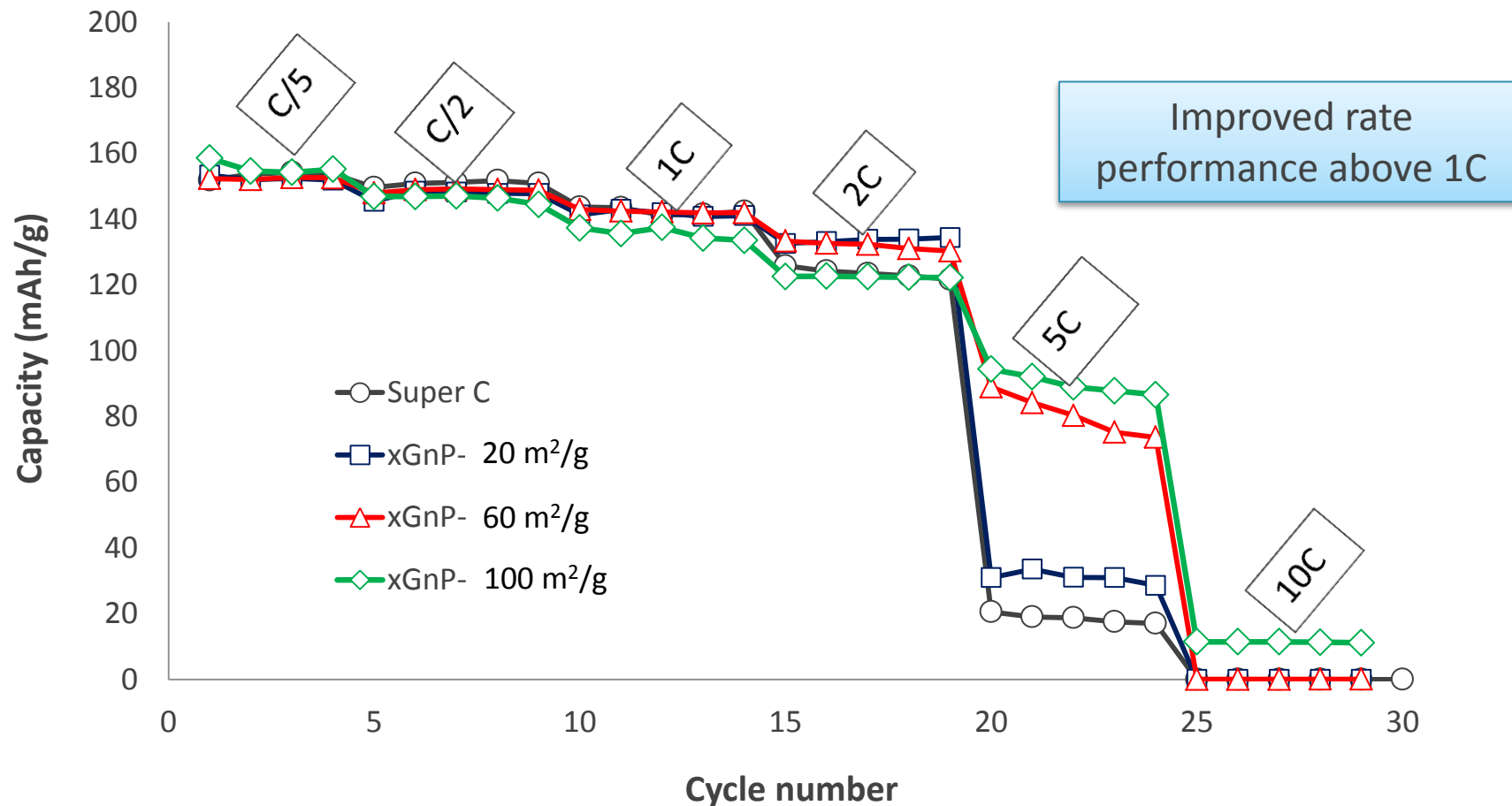
SURFACE & EDGES

1. Electrical conductivity
2. Dispersion quality
3. Mechanical properties
4. Hydrophobic / hydrophilic

XGS's non-GO manufacturing process provides:
• lower cost, • higher strength, • better conductivity

- Energy Storage
 - Electrodes for LIB or supercapacitors
- Thermal Management
 - Heat spreaders for smartphones and tablets, battery packs
- Printed Electronics
 - Low-cost replacement for silver
- Coatings
 - Functional barrier coatings, sensors
- Lubrication
 - Anti-wear additive
- Structural composites – autos, aerospace, wind energy, construction
 - Thermoplastics like PP, PC, PE
 - Thermosets like epoxies, urethanes, acrylics

- **Lithium-ion batteries**
 - Graphene conductive additive
 - High specific energy Silicon/graphene anode
- **Lead-carbon batteries**
 - High charge rate/ cycle life anode
- **Supercapacitors**
 - High specific energy paper electrode
- **Advanced**
 - Li-air battery cathode
 - Li-S battery anode



Cathode: LFP (1.2mA/cm²) on bare Al foil
Binder: PVDF

Electrolyte: 1M LiPF₆ in EC/DMC (1:1)
Electrode formulation: LFP:Binder:CA = 90:5:5

AN-S material is produced using our existing low-cost graphene process

Unique aspects:

- Low-cost Silicon precursor
- Graphite flake
- High-rate manufacturing process

Result:

- Aggregate of Silicon tightly coated by xGnP[®] graphene platelets
- Demonstrates excellent Li ion transport, electrical conductivity, chemical resistance, and mechanical strength with low BET surface area

US Department of Energy Selects XG Sciences to Develop High-Energy Battery Materials

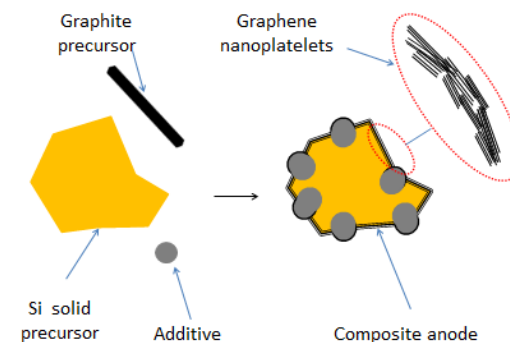
Contract will accelerate commercialization of improved Lithium-ion batteries for electric vehicles

Lansing, Mich. ([PRWEB](#)) October 15, 2012 -- XG Sciences, Inc. announced today it has been selected by the U.S. Department of Energy (DOE) to develop high-energy Lithium-ion battery materials for use in extended range electric vehicle applications. XG Sciences' Silicon-graphene nanocomposite anode materials have demonstrated significant increases in energy storage capacity over traditional graphite and are manufactured with a commercially-proven, low-cost process using widely-available and economical starting materials.

Three key features incorporated to address the cycling stability & cost:

1. Graphene nanoplatelets built into the composite structure

- Provide a large contact area with Si particles,
- Maintain electric contact between electrode components,
- Deliver flexibility to help accommodate Si volume change during cycling,



2. Graphene nanoplatelets are also used as a conductive additive

- Flexible flake morphology provides better particle contact,
- Helps to maintain the mechanical integrity of the electrode.

3. Utilize an existing, low-cost industrial manufacturing process

- XG Sciences is already using the process for bulk production of xGnP[®] graphene nanoplatelets.

AN-S Material description

☐ Particle size

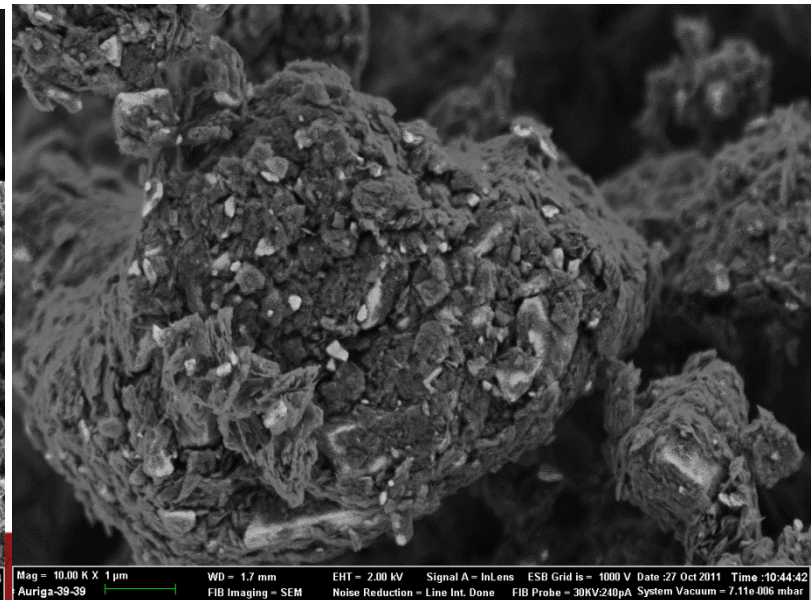
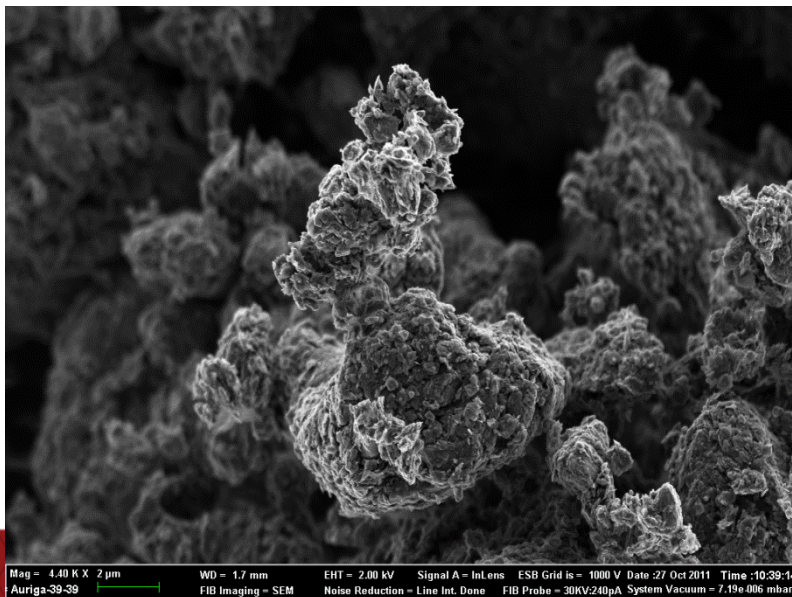
Mean (um)	D10 (um)	D50 (um)	D90 (um)
1.0	0.5	0.8	1.9

☐ Tap density

ANS-101 : 0.88 g/cc vs Commercial nano Si : ~ 0.10 g/cc

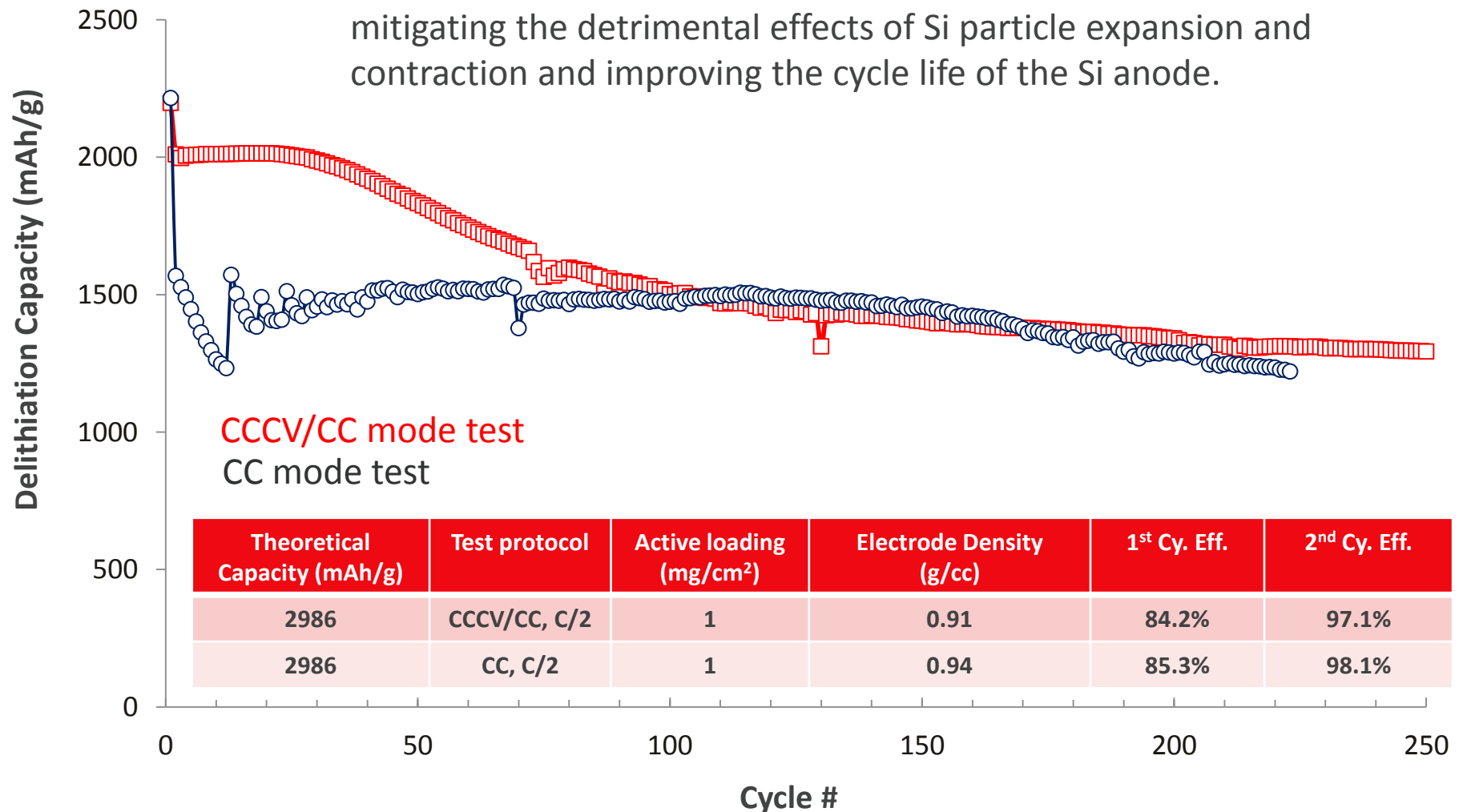
☐ Typical capacity : 2852mAh/g

☐ Morphology

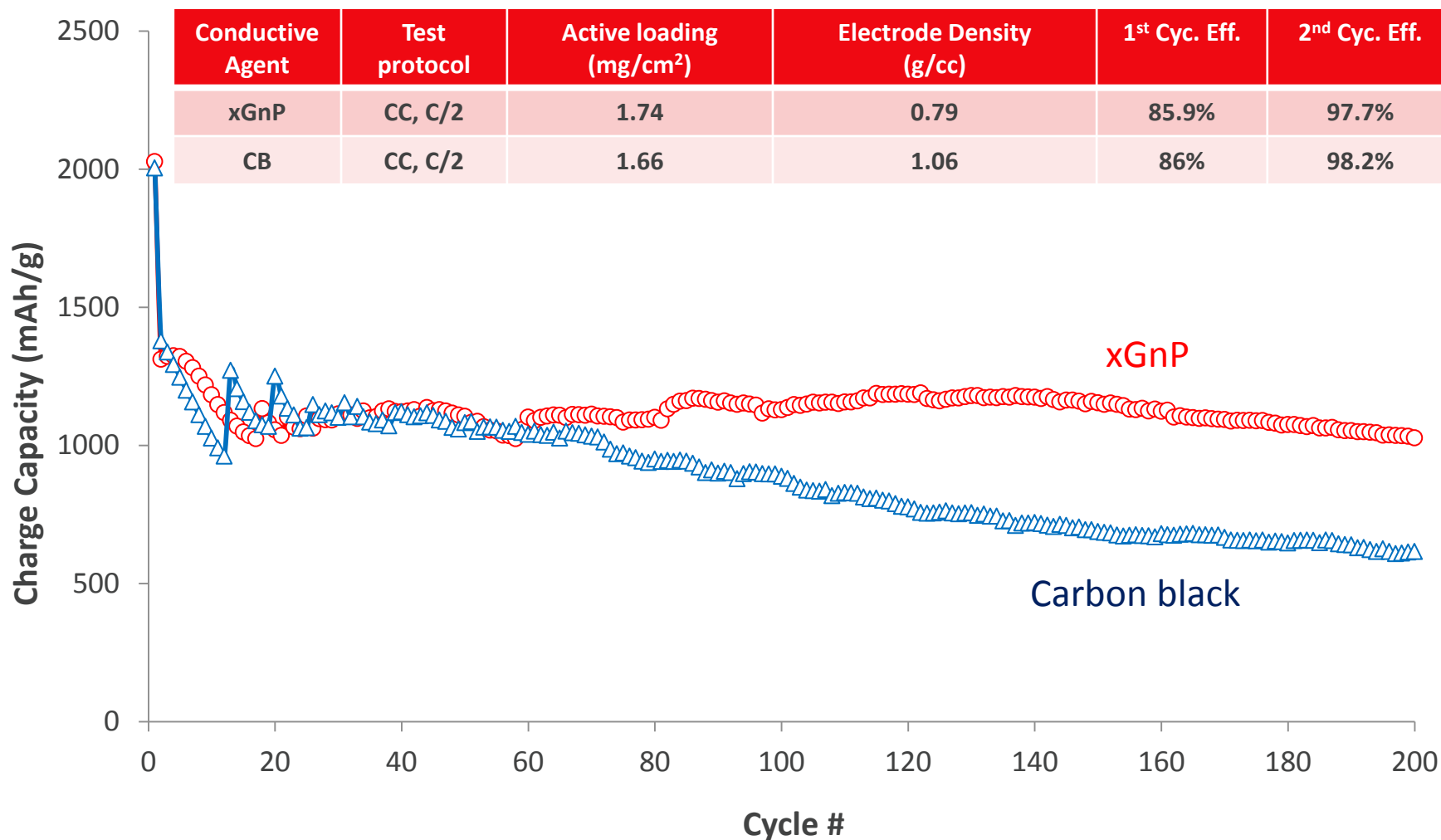


AN-S-101 Performance

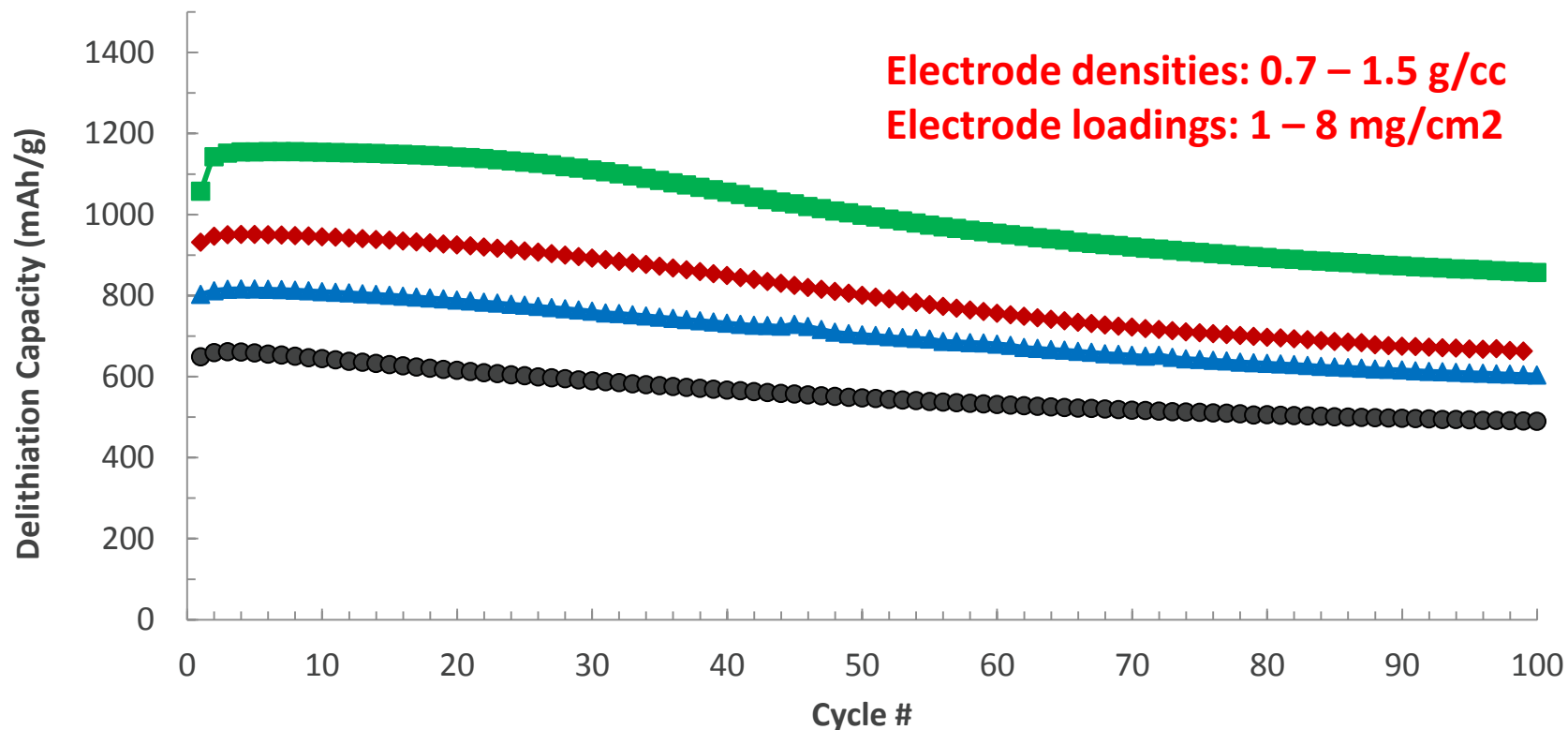
The cycling stability confirms the material design strategy works well in mitigating the detrimental effects of Si particle expansion and contraction and improving the cycle life of the Si anode.



Role of xGnP[®] Conductive Agent

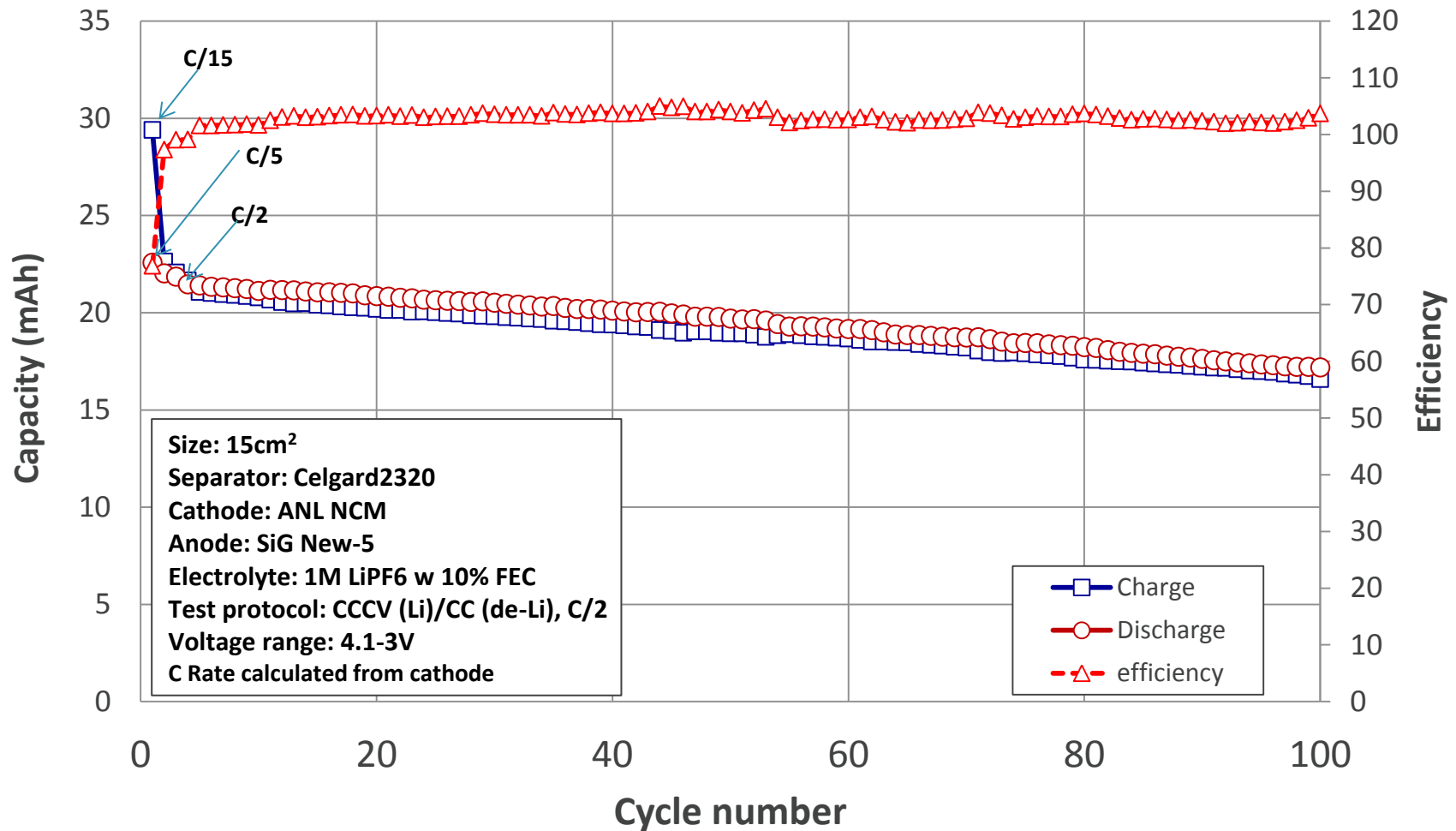


AN-SH Performance



	Active loading (mg/cm ²)	Electrode Density (g/cc)	1 st cycle eff. (%)	2 nd cycle eff. (%)	Test cond.
●	2.89	0.86	90.4	98.2	CCCV/CC, 1C
▲	2.44	0.78	89.3	98.1	
◆	2.84	0.96	88.7	98	
■	2.44	0.96	87	97.9	

AN-SH Full Cell Performance





XG Leaf™ is a thin, flexible, lightweight sheet optimized for in-plane thermal conductivity.

Application:

Heat spreading and thermal management

- Battery packs*
- Portable Electronics
- LED Devices



Product Characteristics

- Thermal conductivity: 500 W/mK (in-plane)
- Adjustable thickness: 25-200 μm
- Adjustable mechanical properties
- 24-in x 24-in sheet

- Highly anisotropic
- Flexible and lightweight
- Self-standing
- Corrosion resistant

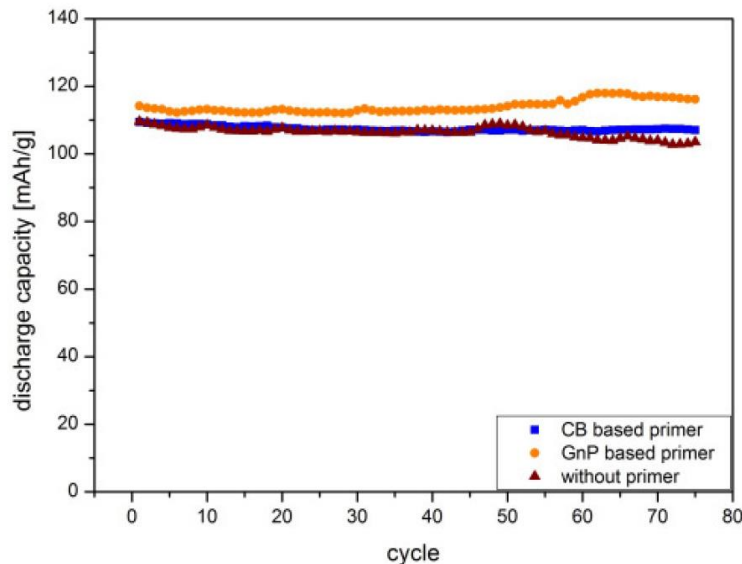
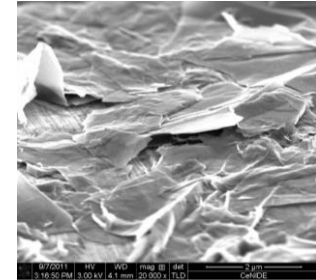
XG Leaf Thermal conductivity

Product	Description	Thermal Conductivity (W/mK)
XG Leaf™	High thermal conductivity 25 – 100+ μm Anisotropic – controlled heat transfer in 2D	400 – 600
Natural Graphite	Limited thermal conductivity	150 – 400
HOPG (Highly Oriented Pyrolytic Graphite)	Expensive High temperature batch process ($> 2000^{\circ}\text{C}$)	500 – 1500
Copper	Lower thermal conductivity Heavy	< 400
Aluminum	Much lower thermal conductivity Corrosive	< 237

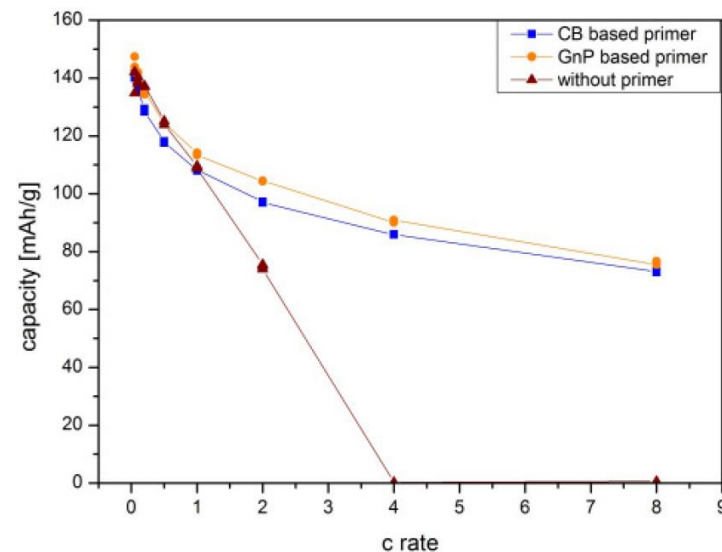
Graphene-coated Al current collectors

Performance of LFP-based cells enhanced through:

- 1) Conductive xGnP[®] graphene interface,
- 2) Surface texture.



(a)



(b)

Discharge capacity (at 1 C) vs (a) cycle number and (b) C-rate for LFP cathodes with xGnP[®] graphene and carbon black coated Al current collectors

- xGnP[®] Graphene Bulk Material
 - LFP Cathode rate performance benefits from xGnP[®] conductive additive
- AN-S Silicon/ graphene anode
 - Capacity 600 mAh/g – 2000 mAh/g
 - 1st cycle efficiency 85 – 90%
 - Stable cycling performance over 200+ cycles
- XG Leaf[™] Graphene sheet heat conductors
 - Provide 500 W/mK (in-plane)/ 5 W/mK (through plane), non-corrosive and light weight
 - 24-in x 24-in sheet product
- Graphene-coated Al current collectors
 - Improve capacity, rate performance and adhesion of LFP cathodes

Materials enabling extending run-time in battery applications

